Evaluation of 10 Methods for Initializing a Land Surface Model

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ABSTRACT

Improper initialization of numerical models can cause spurious trends in the output, inviting erroneous interpretations of the earth system processes that one wishes to study. In particular, soil moisture memory is considerable, so that accurate initialization of this variable in land surface models (LSMs) is critical. The most commonly employed method for initializing an LSM is to spin up by looping through a single year repeatedly until a predefined equilibrium is achieved. The downside to this technique, when applied to continental- to global-scale simulations, is that regional annual anomalies in the meteorological forcing accumulate as artificial anomalies in the land surface states, including soil moisture. Nine alternative approaches were tested and compared using the Mosaic LSM and 15 yr of global meteorological forcing. Results indicate that the most efficient way to initialize an LSM, if possible and given that multiple years of preceding forcing are not available, is to use climatological average states from the same model for the precise time of year of initialization. Three other approaches were also determined to be preferable to the single-year spinup method. In addition, low-resolution spinup scenarios were devised and tested, and based on the results, an effective yet computationally economical technique is proposed.

1. Introduction

Land surface models (LSMs) simulate the physical processes that partition precipitation and solar radiation after they reach the ground. LSMs enable spatially and temporally continuous and physically consistent estimates of soil moisture, surface temperature, evapotranspiration, and other terrestrial stocks and fluxes of water and energy to be produced in an economical manner. Thus LSMs are valuable tools for studying the water and energy cycles and are important components of weather and climate prediction systems.

In addition to the shortcomings inherent to any parsimonious numerical representation of highly variable and nonlinear physical processes, the fidelity of LSM simulations is limited by the accuracy of the input fields (static parameters and meteorological forcing) and initial conditions. Initial conditions for a land surface model are the spatially varying set of fields that describe the surface water and energy states at the instant a simulation begins. These may include the water content and temperature of each soil layer, the depth, heat content, density, and liquid water storage of the snowpack, canopy water content, and other properties of the vegetation. All else being the same, "perfect" initial conditions actually vary among LSMs because the climatology of each model is determined largely by its

physics (e.g., Koster and Milly 1997). The input forcing data and vegetation, soil, and topographical parameters can affect LSM climatology as well. Because model climatologies tend to differ from those observed in nature, perfect initial conditions are not necessarily faithful depiction of the earth. Instead, they are the set of states that would result from a long-term simulation of a stable LSM with a consistent forcing dataset. Flawed initial conditions may produce fallacious trends as the state variables drift back toward the modeled ideal, potentially leading to inaccurate assessments of interannual- to climate-scale variations. Hence careful attention to the initialization procedure is critical in any model-based study.

Long-term, consistent forcing datasets are rarely available for spinning up a land surface model toward perfect initial conditions. Furthermore, multiyear simulations can be computationally expensive, depending on the spatial resolution and coverage. So modelers resort to other methods for spinning up or otherwise initializing their LSMs. Perhaps the most common method is to loop repeatedly through a single year. When the land surface states and/or fluxes equilibrate (cease to vary appreciably from year to year), the spinup is considered complete and the experimental simulation is allowed to commence. For example, the 10 groups that participated in the Global Soil Wetness Project (Dirmeyer et al. 1999) spun up their land surface models by looping through integrations with 1987 forcing data for 2 to 10 repetitions.

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Spinup time was defined in the Project for Intercomparison of Land Surface Parameterization Schemes (PILPS) Phase 1 as the number of yearly integrations necessary to yield changes in annual mean latent and sensible heat fluxes that were less than 0.1 W m^{-2}. Based on this definition, Yang and Dickinson (1995) found that the spinup times for 22 PILPS phase 1 LSMs running on a single point and starting from a middling moisture condition ranged from 2 to 10 yr for a tropical forest and from 2 to 15 yr for a midlatitude grassland site. Adding the constraint that root zone soil moisture must not change more than 0.1 mm and starting from saturation, Chen et al. (1997) found that the spinup times for 23 PILPS phase 2 models varied from 1 to 60 yr for a grassland site in the Netherlands. Others have defined spinup time based on *e*-folding time (Delworth and Manabe 1988) or halving time (Simmonds and Lynch 1992). The downside to the single-year loop technique is that 1 yr cannot provide an accurate climatology, and any regional meteorological anomalies will accumulate as anomalies in the land surface states until an unnatural equilibrium is achieved (Schlosser et al. 2000). Spinup time also varies depending on the conditions prescribed at the outset. Cosgrove et al. (2003) compared three initialization techniques, a wet initialization, a dry initialization, and initialization by output from the National Centers for Environmental Prediction and Department of Energy Global Reanalysis 2 (NCEP/DOE R-2; Kanamitsu et al. 2002). They found that the last produced a substantial reduction in spinup time for all four LSMs in the study despite the differences between the NCEP/DOE R2 climatology and those of the LSMs. Walker and Houser (2001) demonstrated that spinup time could be reduced through the assimilation of observation-based surface soil moisture data; however that technique was not evaluated here.

The following sections describe and assess 10 initialization and spinup methods and one hybrid of two promising methods. The experiments were motivated by a desire to initialize LSMs in a way that would minimize the adverse effects of imperfect initial conditions given a shortage or complete lack of background forcing, also taking into account that computer processing time may be limited. Mosaic was the LSM used in the experiments (save for two in which Noah LSM states were used to initialize Mosaic); however, the relative outcomes are expected to be essentially model independent. Soil moisture was the only state variable examined here, which simplified the comparisons. Soil temperature has less variational inertia than soil moisture and also less interannual variability, so that it reaches equilibrium during spinup in much less time than root zone or total column soil moisture (Houser et al. 1999; Cosgrove et al. 2003). Initialization of snow water equivalent, which has no upper bound, is beyond the scope of this work.

5. Summary and conclusions

Ten methods for initializing land surface models were evaluated by initializing one 1987–93 Mosaic LSM simulation with each and comparing the output total column soil moisture fields with those from a "truth"

run which spanned 1979–93. The most commonly applied method, when a long-term forcing dataset is not available for spinup, is looping repeatedly through a single year until a desired level of equilibrium is achieved. Its disadvantage is that forcing anomalies in the looped year accumulate as artificial anomalies in the initialized land surface states. The desire to identify a more efficient method motivated this study, and the results demonstrate that certain other techniques are superior. In particular, initialization with model-specific mean state fields for the precise time of year proved to be optimal.

Primary nonmeteorological controls on soil moisture spinup time include the soil column depth, hydraulic conductivity (determined by soil type, degree of wetness, and model specific parameters), rooting depth, and the persistence of snow cover. All of these factors regulate the influence of atmospheric forcing on moisture storage. A given weather event (rain or period of dry sun) is more likely to change the soil wetness significantly in the deepest layer if the soil is shallow, coarse, vegetated, and lacking snow cover. In the experiments, alpine and Northern regions that were snow covered for part or all of the year spun up slowly or not at all. Soil columns are often assigned 2-m or shallower depths in LSM simulations, which would likely result in spinup times that are shorter than those exhibited here.

The primary meteorological controls on spinup times are freezing temperatures and precipitation. Freezing halts infiltration and redistribution of soil water and encourages the accumulation of snow. In the experiments, humid regions spun up much more quickly than arid regions, and deserts such as the Sahara were very slow to adjust after an overly wet or overly dry initialization. For the reasons outlined in this and the previous paragraph, large-scale simulations that encompass many soil, vegetation, and climate types often will be slower to approach appropriate moisture conditions throughout the domain than smaller-scale, more homogeneous simulations where the range of soil wetness, and thus the difficulty in selecting an initial value, is reduced.

If forcing availability, time, and computer resources are not issues, then allowing a model to integrate through the years (as many as possible) leading up to the start of an experimental period is the best way to initialize a simulation. That is rarely the situation. If multiple years of forcing are available but all or most are within the experimental period, then the following technique is suggested. First, the spinup should start from middling to wet initial states and loop through all available years of forcing until a desired level of equilibrium is attained. Next, the mean state fields for the precise time of year of the start of the experimental period should be computed based on output from the last complete loop. These fields should then be used to initialize the experiment. If it is an issue, computing time can be reduced by performing all or part of the spinup procedure at a low spatial resolution and later interpolating to the desired resolution. These recommendations are based on tests with the Mosaic LSM, but the relative effectiveness of the initialization techniques are likely to apply to other models.